10/561788

P801325/WO/1

IAP9 Rec'd PCT/PTO 21 DEC 2005

DaimlerChrysler AG

Stabilizing device, vehicle equipped therewith, and stabilizing method

The invention relates to a stabilizing device for stabilizing a vehicle with regard to driving dynamics, having presetting means for determining a setpoint yaw rate signal and having limiting means for determining a limiting yaw rate signal which represents a maximum yaw rate of the vehicle, in such a way that the vehicle remains stable while taking into account the maximum yaw rate, and for limiting the setpoint yaw rate signal to the limiting yaw rate signal when the value of the setpoint yaw rate signal exceeds the value of the limiting yaw rate signal. The invention also relates to a single-track or multitrack vehicle having such a stabilizing device and to a method with the mode of functioning of such a stabilizing device.

Such a stabilizing device is known, for example, in the context of a driving dynamics controller of a vehicle, for example of a passenger car, from the article "FDR-Die Fahrdynamikregelung von Bosch [FDR - the driving dynamics controller from Bosch]", ATZ Automobiltechnische Zeitschrift 96 (1994) 11, pages 674 to 689, editor Anton van Zanten, Rainer Erhardt and Georg Pfaff. The control concept of the known driving dynamics controller is based on the so-called single-track model in which a setpoint yaw rate is calculated from the speed of the vehicle and from a presetting steering angle which the driver presets at a steering handle. However, if an excessively large setpoint yaw rate is selected the vehicle could not travel along the desired curved path due to the wheels' frictional properties being too low or the like, for example, if the setpoint yaw rate is limited by the driving dynamics controller. The interventions of the

driving dynamics controller in the brakes and/or the engine of the vehicle take place on the basis of the limited setpoint yaw rate. In order to determine the setpoint yaw rate, the presettings of the driver of the vehicle with respect to the steering angle and the drive torque and braking torque, the estimated speed of the vehicle and the coefficient of friction of the wheels are evaluated.

The known stabilizing device is primarily intended to prevent the vehicle from skidding. However, it is also problematic if the vehicle tilts and possibly even rolls over.

The object of the invention is therefore to improve a stabilizing device or a method of the type mentioned at the beginning to the effect that a risk of tilting of the vehicle is reduced.

In order to achieve the object, with the stabilizing device of the type mentioned at the beginning there is provision for said stabilizing device to have actual value means for making available a tilt angle signal which represents the current tilt angle of the vehicle, for the limiting means to contain tilt angle means for determining the limiting yaw rate signal by reference to the tilt angle signal, and for said stabilizing device to have generating means for generating a steering intervention signal and/or at least one braking intervention signal by reference to the limited setpoint yaw rate signal. In a corresponding way, a vehicle according to the invention and a method according to the invention are designed in accordance with the technical teaching of a further independent claim.

The tilt angle, sometimes also referred to as the rolling angle, describes the rotational deflection of

the vehicle about its longitudinal axis. Taking into account the tilt angle in the determination of the setpoint yaw rate signal which is the maximum permitted prevents the vehicle from tilting or even rolling over. The generating means are, for example, a yaw rate controller. The steering intervention signal controls, for example, a steering actuator for steering the wheels of one axle. Brake actuators are actuated using the braking intervention signal or a plurality of braking intervention signals. The stabilizing device is preferably what is referred to as a steer-by-wire controller. The stabilizing device can however also form a component of a driving dynamics controller of the vehicle.

Advantageous embodiments of the invention emerge from the dependent claims and from the description.

The stabilizing device additionally expediently takes into account the current attitude angle of the vehicle. The attitude angle is the angle between the longitudinal axis of the vehicle and the vector of the speed of the vehicle. The attitude angle signal which represents the attitude angle of the vehicle is made available by the correspondingly designed actual value means. The limiting means expediently contain attitude angle means for determining a second, attitude-angle-dependent limiting yaw rate signal. The limiting means limit the value of the setpoint yaw rate to the value of the tilt-angle-dependent yaw rate or the attitude-angle-dependent yaw rate, depending on which of the two yaw rates is lower.

The tilt angle signal may contain the current tilt angle of the vehicle. However it is also possible for the tilt angle signal to contain values from which the tilt angle can be determined. In principle the same also applies to the attitude angle signal which may

specifically contain the current attitude angle of the vehicle. However it is also possible for it to contain values from which the vehicle attitude angle can be determined, for example inter alia the lateral speed of the vehicle and the longitudinal speed of the vehicle.

One selection method has proven advantageous for the limiting means: the limiting means select the setpoint yaw rate signal as an input signal for the generating means if the value of said signal does not exceed the value of the (first) tilt-angle-dependent limiting yaw rate signal and otherwise the limiting yaw rate signal, that is to say the maximum value of the yaw rate which is responsible for the driving stability of the vehicle. If the second limiting yaw rate signal which is dependent on the attitude angle of the vehicle is additionally made available to the limiting means, the limiting means select, for example, the yaw rate signal which is smallest in absolute value as an input yaw rate signal for the generating means, for example the yaw rate controller.

At this point the following is to be noted: the term yaw rate signal used above is used in conjunction with the setpoint yaw rate signal and the limiting yaw rate signal. That is to say the yaw rate signal is a signal which represents a preset value and which corresponds either to the setpoint yaw rate signal or the limiting yaw rate signal depending on what the selection has yielded. If the term yaw rate signal is used, setpoint yaw rate signals or limiting yaw rate signals are meant. The significance presented here for the two terms yaw rate signal or yaw rate signals is also intended to apply to their use below.

The presetting means are expediently based on at least one reference model of the vehicle. This may be, for example, an essentially real image of the vehicle.

However, it is also possible for a desired behavior of the vehicle, for example a sporty or comfortable desired behavior to be selected as a reference model. In one expedient embodiment of the invention, such desired models can also be selected by a driver of the vehicle.
A reference model is composed, for example, of one or more differential equations which describe the behavior of the vehicle.

The actual value means expediently contain measuring means and/or estimating means. The measuring means are, for example, the vehicle sensor systems, for example rotational speed sensors, a yaw rate sensor, lateral acceleration sensors or the like. The estimating means preferably contain an observer. The observer is expediently not linear. The observer is, for example, what is referred to as a Kalman filter.

The actual value means accordingly make available real and/or estimated actual values. These actual values expediently form input values for the limiting means and contain, for example, the tilt angle signal and/or the attitude angle signal. It goes without saying that such an observer can also form a component of the limiting means.

The actual value means are expediently connected directly to the generating means. The actual value means advantageously make available input values for the generating means. It is also expedient for the generating means to make available input values for the actual value means.

The yaw rate signals are advantageously dependent on the direction of rotation. For example, a negative value of a yaw rate signal is available for left-handed rotation and a positive value is available for right-

handed rotation of the vehicle about its vertical vehicle axis. In a corresponding way, limiting means are designed to limit the setpoint yaw rate signal in terms of absolute value. For example, the tilt angle means and the attitude angle means in such a configuration respectively make available a positive and a negative maximum limiting yaw rate value. The lower and the upper limiting values may be contained in the first, tilt-angle-dependent or the second, attitude-angle-dependent limiting yaw rate signal. The same applies correspondingly to the setpoint yaw rate signal generated by the presetting means.

The stabilizing device according to the invention is expediently designed in such a way that the vehicle does not roll over while taking into account the maximum yaw rate. Correspondingly, the limiting means are designed to determine the limiting yaw rate signals which are necessary to avoid a vehicle rollover.

The means of the stabilizing device according to the invention may be embodied using hardware and/or software. The stabilizing device expediently contains program code which can be executed by means of a control means, in particular a processor, a driving stability controller and/or a steering controller of the vehicle. The steering controller is, for example, the steering system of a steer-by-wire system.

The stabilizing device according to the invention is preferably applied in multitrack vehicles, for example passenger cars or utility vehicles. The stabilizing device can also be used in single-track vehicles, for example motorbikes.

The setpoint yaw rate signal is advantageously determined as a function of a preset steering angle signal and a variable which represents the speed of the

vehicle. The determination can be carried out using a mathematical model which is based on the Ackermann relationship, for example.

The invention will be explained in more detail below using an exemplary embodiment and with reference to the drawing.

The figure shows a vehicle according to the invention having a stabilizing device according to the invention.

A vehicle 10, for example a passenger car with an internal combustion engine (not illustrated) has a front axle 11 with steerable wheels 12, 13 and a rear axle 14 with non-steerable wheels 15, 16. Brakes 17, 18, 19, 20 for braking the respective wheel 11, 12, 15, 16 and rotational speed sensors 21 to 24 for sensing the respective rotational speed of the wheel 11, 12, 15, 16 are arranged on the wheels 12, 13, 15, 16. The brakes 17 to 20 can be controlled by a stabilizing device 25 by means of braking intervention signals 26 to 29 (represented schematically by arrows). The rotational speed sensors 21 to 24 transmit, to the stabilizing device 25, rotational speed signals 30 to 33 which represent the respective rotational speed of the wheel 12, 13, 15, 16.

A driver 36 can predefine a direction request δ_H, which is sensed by a steering angle sensor 37, at a steering wheel 35 or some other steering handle. The steering angle sensor 37 generates a preset steering angle signal 38 and transmits it to the stabilizing device 25. The stabilizing device 25 generates, inter alia, a steering angle signal 39 while taking into account the preset steering angle signal 38, and transfers the steering angle signal 39 to a steering actuator arrangement 40, which contains, for example, an actuating motor or the like. The steering actuator

arrangement 40 steers the wheels 12, 13 of the front axle 11. In principle, the stabilizing device 25 could also send a steering intervention signal (not illustrated in the figure) to a steering actuator (not illustrated) which is assigned to the rear axle 14, for example if the vehicle 10 were to have a rear-axle steering system and/or a combined front-axle or rear-axle steering system.

The stabilizing device 25 contains here what is referred to as a steer-by-wire control circuit with presetting means 41, a yaw rate controller 42 which forms generating means according to the invention, sensing and outputting means 43 and an observer 44. In addition, limiting means which are referred to overall by the reference number 45 and which contain tilt angle means 46, attitude angle means 47 and selection means 48 are present.

The stabilizing device 25 is based, for example, on a vehicle model with three degrees of mechanical freedom. In addition to the attitude angle β and the yaw rate ψ, the rolling angle φ describes the current position of the vehicle 10. The following movement equations (1) - (3) of the vehicle 10 can be derived from the law of momentum in the lateral direction and the law of conservation of angular momentum about the vertical axis and the longitudinal axis of the vehicle 10. In this context, variables which are transformed to a horizontal coordinate system are used to describe the state of the vehicle.

$$\dot{\beta} = -\dot{\psi} + \frac{1}{mv_x}\{F_{S,V} + F_{S,H}\} \qquad (1)$$

$$\ddot{\psi} = A(\dot{\psi},\varphi,\dot{\varphi}) + B(\varphi)\{l_V F_{S,V} - l_H F_{S,H} - M_{\psi\beta}\} \qquad (2)$$

$$\ddot{\varphi} = C(\dot{\psi},\varphi,\dot{\varphi}) + D(\varphi)\{F_{S,V} + F_{S,H}\} \qquad (3)$$

In the equations (1) to (3), $F_{s,v}$ + $F_{S,H}$ are the side forces at the front axle and the rear axle and l_v and l_h are the distances between the center of gravity and the front axle and rear axle, respectively. The functions A and C describe non-linear elements which can be compensated by control technology. The function B corresponds approximately to the tilt-angle-dependent reciprocal value of the moment of yaw inertia. The function D corresponds approximately to the tilt-angle-dependent quotient formed from the height of the center of gravity and the moment of rolling inertia.

In vehicles which can be steered at the front axle, the lateral force can be changed directly at the front. The lateral force of the rear axle can be influenced by means of a braking intervention and/or by steering the rear axle. Otherwise, the lateral force occurs at the rear owing to vehicle parameters, tire parameters and ambient parameters. The control approach which is selected by way of example is based on a front axle steering system with an optional single-wheel braking intervention, for example by means of the braking intervention signals 26 to 29. The present design of the yaw rate controller 42 or of the tilt angle means 46 is expediently made using methods of non-linear control technology, for example with a Ljapunov function.

In the stabilizing device 25, the Ljapunov function V is, for example as follows:

$$V = \frac{1}{2}(\dot{\psi} - \dot{\psi}_{Soll})^2 + \frac{1}{2}k_1(\dot{\varphi} - \dot{\varphi}_{Soll})^2 + \frac{1}{2}k_2(\varphi - \varphi_{Soll})^2, \quad k_1, k_2 > 0 \qquad (4)$$

For the stability of the overall system it is required that the function V be positively semidefinite and its time derivate be negatively definite. The following therefore results:

$$V \geq 0, \quad \dot{V} < 0 \qquad (5)$$

If the movement equations (1) to (3) are inserted into the Ljapunov function (4), a feedback law can be established for the yaw rate controller 42, said law compensating the non-linear components and being stabilized by linear components. This results in the following formula:

$$F_{SV} = \frac{1}{D(\varphi)(l_V + l_H)}\left\{-A(\dot{\psi}, \varphi, \dot{\varphi}) + B(\varphi)l_H ma_y + \ddot{\psi}_{Soll} - \lambda_1(\dot{\psi} - \dot{\psi}_{Soll})\right\} \qquad (6)$$

The yaw rate controller 42 can generate the steering intervention signal 39, which contains a wheel steering angle, from the lateral force at the front axle F_{SV}.

In a way which is analogous to the lateral force at the front axle F_{SV}, a setpoint yaw rate $\dot{\psi}_{Soll}$ at which the overall system experiences transient recovery in a stable fashion about a tilt angle φ can also be determined from the Ljapunov function (4). The following formula (7) forms the basis for the tilt angle means 45 which can also be referred to as a tilt angle limiting controller.

$$\dot{\psi}_{Soll} = \frac{1}{mB(\varphi)v_x}\left\{-C(\dot{\psi},\varphi,\dot{\varphi}) - mD(\varphi)(a_y - \dot{\psi}v_x) + \ddot{\varphi}_{Soll} - \lambda_2(\dot{\varphi} - \dot{\varphi}_{Soll}) - \lambda_3(\varphi - \varphi_{Soll})\right\} \quad (7)$$

Here, the coefficients λ_1, λ_2, λ_3, which determine the control dynamics are expediently selected as positive definite values in order to stabilize the system.

The stabilizing device 25 is designed in the present case in such a way that it limits the rolling/tilting movement of the vehicle 10 only when there is the risk of tilting or rollover of the vehicle 10. The function of the attitude angle means 47, which can also be referred to as an attitude angle limiting controller in the present case, remains uninfluenced by the use of the tilting angle means 46 and the selector means 48. In a highly simplified way it is possible to state that the attitude angle means 47 prevent skidding of the vehicle 10, and the tilt angle means 46 prevent tilting of the vehicle 10 in conjunction with the selector means 48. In this context, the selector means 48 assume a limiting function, which will be explained in more detail below.

The presetting means 41 form a setpoint yaw rate signal 49 with reference to the preset steering angle signal 38 and a variable which represents the speed of the vehicle. The variable which represents the speed of the vehicle is, for example, contained in a driving state signal 56 which will be described below. This setpoint yaw rate signal 49 generally forms the input variable for the yaw rate controller 42. However, the steering request of the driver 36 cannot be implemented in the desired way in every driving situation of the vehicle 10. The setpoint yaw rate signal 49 is monitored by the limiting means 45 and if necessary limited to a limiting yaw rate signal. In the present case, the selector means 48 are provided with a first limiting

yaw rate signal 50 by the tilt angle means 46 and with a second limiting yaw rate signal 51 by the attitude angle means 47, said second limiting yaw rate signal depending on the current attitude angle rate of the vehicle 10. The selector means 48 select the setpoint yaw rate signal 49 if it is smaller in absolute terms than the limiting yaw rate signals 50, 51. Otherwise, the selector means 48 select the limiting yaw rate signal 50 or 51 which is smaller in absolute terms.

The yaw rate signals 49 to 51 are dependent on the direction of rotation here, that is to say they are provided, for example, with a sign. This applies both to the setpoint yaw rate signal 49 and to the limiting yaw rate signals 50 and 51. Correspondingly, the limiting yaw rate signals 50, 51 each contain an upper limiting value and a lower limiting value. It would also be possible to use the term limiting yaw rate for a right-handed bend or a limiting yaw rate for a left-handed bend, and these are respectively defined by the tilt angle means or the attitude angle means 46, 47. The yaw rate controller 42 generates output signals 52 which may contain, for example, the steering intervention signal 39. The output signals 52 are sensed by the sensing and output means 43 and transferred to the actuator system of the vehicle 10, for example the brakes 17 to 20. The sensing output means 43 output, for example, the braking intervention signals 26 to 29 and sense the rotational speed signals 30 to 33.

The sensing means 43 and the observer 44 form components of actual value means 53. The actual value means 53 measure and estimate system states of the vehicle 10, in which case they evaluate, for example, the rotational speed signals 30 to 33 in order to determine the lateral speed and longitudinal speed of the vehicle 10. Non-measurable system values, which

may, however, be required, for example, by the tilt angle means 46, are determined, as it were estimated, by the observer 44, which can accordingly also be referred to as an estimating means.

The observer 44 contains, for example, a Kalman filter and estimates, for example, an attitude angle, a tilt angle, a tilt angle speed or the like of the vehicle 10 by reference, for example, to the steering angle, the longitudinal speed of the vehicle, the lateral acceleration and a yaw rate which the sensing means 43 transmit to the observer within the scope of a signal 57. However, in principle the spring paths at the wheels 12, 13, 15, 16 until one of the wheels lifts off could also be determined so that it would be possible to determine the tilt angle and tilt angle rate as measured variables.

The current yaw rate of the vehicle 10 is determined by a yaw rate sensor 55 and this is transferred to the stabilizing device 25 within the scope of an actual yaw rate signal 54.

The observer 44 sends a driving state signal 56 to the presetting means 41 and the attitude angle means 47 and the tilt angle means 46. The driving state signal 56 contains, for example for the tilt angle means 46, the current tilt angle and/or the current tilt angle rate of the vehicle 10. For the attitude angle means 47, for example the attitude angle and/or the attitude angle rate and/or the longitudinal speed of the vehicle and the lateral speed of the vehicle 10 are contained in the driving state signal 56 of the vehicle 10. The driving state signal 56 contains, for example, a tilt angle signal and an attitude angle signal. The longitudinal speed of the vehicle which is contained in the driving state signal 56 and which constitutes a variable which represents the speed of the vehicle is

fed to the presetting means 41 for determining the setpoint yaw rate signal 49.

The yaw rate controller 42 and the observer 44 are also expediently connected directly to one another. This optional configuration of the stabilizing device 25 is therefore shown in dashed lines. The observer 44 transfers the driving state signal 56 to the yaw rate controller 42. In the reverse direction, the yaw rate controller 42 transfers its output signals 52, that is to say the presetting variables for the vehicle actuator system, to the observer 44.

It goes without saying that the driving state signal 56 whose contents are determined and/or estimated by the actual value means 53 can also contain further signals, for example the longitudinal inclination and/or the lateral inclination of the underlying surface on which the vehicle 10 is moving. It is also possible, for example, for what is referred to as a Correvit sensor, which can determine the lateral speed of the vehicle and longitudinal speed of the vehicle or alternatively the attitude angle of the vehicle 10, to be provided at the vehicle 10.